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High Efficiency TFT-OLED Display with Iridium-Complex As Triplet Emissive Center

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Abstract

We developed TFT-OLED displays using triplet emissive materials. We used Iridium-Complex as triplet emissive center for the OLED. The displays show high efficiency and excellent image uniformity by 6bit digital gray-scale. We achieved the excellent gray-scale by using high-speed p-Si TFT.

Introduction

TFT-OLED (Organic Light-Emitting Diode) displays have attracted much attention as the candidate of novel type of display. The display can achieve high-resolution with low power consumption. We have developed the TFT-OLED displays to obtain the excellent feature[1,2]. In 1995, TDK Corporation and Semiconductor Energy Laboratory Co., Ltd. presented p-Si TFT-OLED display for the first time in the world[3].

The conventional type of TFT-OLED displays is controlled by analogue voltage to drive the OLED pixels. However, it is difficult to obtain good image uniformity all over the display.

We presented the TFT-OLED display using digital gray-scale combined with time-ratio gray-scale control in SID '00[4]. The display used high-speed p-Si TFT showed good image uniformity[5,6].

Recently triplet emissive material is very interested in for its high efficiency. In 1991, Tsutsui et al proposed the use of triplet excited state in OLED for the first time[7]. Further, Baldo and Tsutusi demonstrated high efficiency by using Iridium-Complex as triplet emissive center[8,9,10].

We developed the TFT-OLED display with triplet material. The display shows good power consumption with high luminance and good image uniformity.

Time-Ratio Gray-Scale Control

Driving method of OLED

Figure 1 shows a circuit of the OLED pixel we used. Tr1 is a switching transistor, which addresses signal to the OLED. Tr2 is a driving transistor, which controls the current flow of the OLED. Cs is storage capacitor to hold signal charge when the signal is applied from the

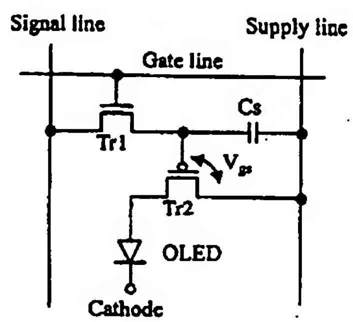
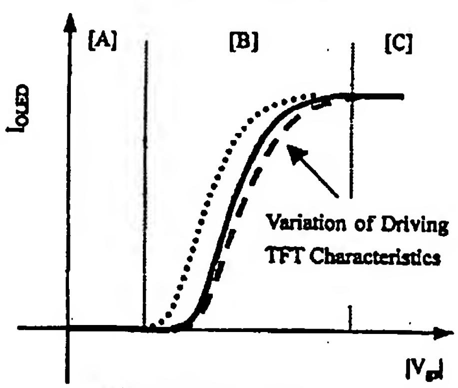
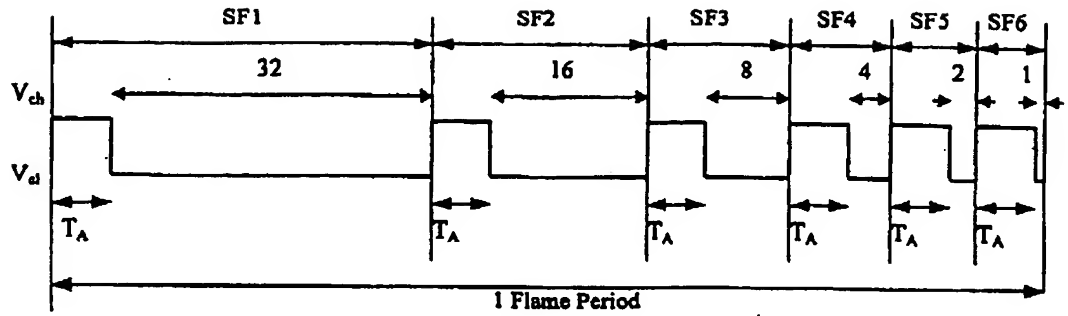


Figure 1 Pixel Circuit



[A]: OFF state of digital gray scale
[B]: Field of analogue gray-scale
[C]: ON state of digital gray scale

Figure 2 Current of OLED



SF1-SF6: Sub Flame Period, T_A: Addressing Period

Figure 3 Timing Chart of Cathode Voltage

source line.

When the gate line is selected, the current flows Tr1 from the source line, and the signal voltage is charged the Cs. The current controlled by the voltage between gate and source of Tr2 (V_{gs}) flows Tr2 and OLED pixel. Therefore Vgs can control luminance of the OLED pixel.

After selecting of Tr1, Tr1 becomes off state and the voltage of Cs (V_{gs}) is kept. Therefore the current, which depend on Vgs, keep flowing.

Figure 2 shows a relation between the current flow of OLED pixel and absolute value of V_{gs} ($|V_{gs}|$). When $|V_{gs}|$ is small, the field [A] in Figure 2, the OLED pixel does not emit because the OLED current is negligibly small. When $|V_{gs}|$ increases, the OLED current starts to flow, and the OLED pixel starts to emit. As the $|V_{gs}|$ increases, the field [B], the luminance of OLED pixel becomes brighter because the OLED current increases. If $|V_{gs}|$ is larger, the field [C], luminance saturates because applied voltage of OLED pixel approaches to the voltage of supply line.

The method to control gray-scale

Analogue gray scale method modulates the luminance of OLED by controlling the current of OLED pixel directly. In case of TFT-OLED, gate voltage of Tr2 is controlled. However, there is a variation of current, which flows each OLED pixel. Even if same voltage is applied to gate of Tr2, the current flows change because of the variation of threshold voltage and mobility of TFT, illustrated in Figure 2. Accurate gray-scale by analogue gray-scale method is difficult.

We adopt digital gray-scale method to avoid the variation of characteristics of the TFT. The gray-scale is controlled by switching between the OFF-state voltage, the field [A] in Figure 2, and ON-state voltage, field [C] in the figure. In this method the variation of characteristics of driving TFT does not affect gray scale control because I_{OLED} is independent of V_{gs} in the field [A] and [C].

However, only two gray-scales can be controlled as it is, therefore we combined the time-ratio gray-scale with the digital gray-scale. Figure 3 shows the timing chart of this method. A flame period is divided to plural sub-flame periods. In case of 6bit gray scale, the flame period is divided to 6 sub-flame periods. The ratio of each emitting periods is 32:16:8:4:2:1. If the emitting period is shorter than the addressing period, each period are overlapped. Therefore two scanning lines must be selected simultaneously. We make the pixel turn off if the emitting period is finished.

At the addressing period, the signal is applied to the gate of driving TFT in a whole pixel area and the charge is stored. The voltage of cathode is the high voltage (V_{ch}), which is equal to the voltage of supply line. The whole OLED pixel do not emit because there are no current flow to OLED pixel.

At the emitting period, the voltage of cathode is low voltage (V_{cl}), which is different from the voltage of supply line. The current flows at the pixel whose voltage is ON-state voltage, and OLED starts to emit. If the Vgs is OFF-state voltage, the current does not flow and OLED does not emit.

At the end of emitting period, cathode voltage is equal to supply line and whole OLED pixel turn off, and it moves the next sub-flame.

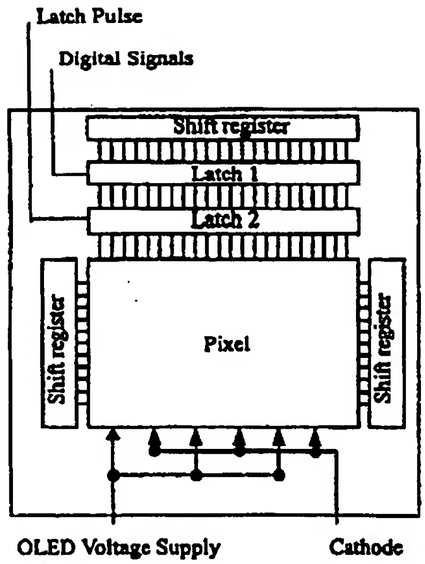


Figure 4 Circuit diagram of TFT-OLED display

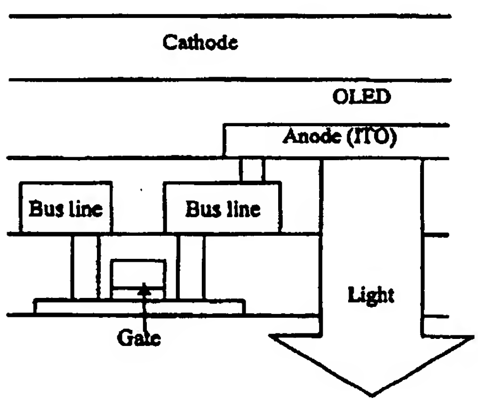


Figure 5 Cross section of the TFT-OLED

Circuit Configuration

Figure 4 shows the driving circuit of the TFT substrate. The pixel circuit, the gate and source driver is made on the same substrate. The pixel circuit and driver are designed for the use of digital driving. Therefore the variation of characteristics of TFT does not affect driving circuit.

Figure 5 shows the cross section of the pixel area of the substrate.

OLED Materials

We used tris (2-phenylpyrimidine) iridium doped in the 4,4'-N,N'-dicarbazole-biphenyl. We also made a singlet TFT-OLED display to compare the triplet material. Figure 6 shows a structure of the OLED used in TFT display.

The response time of triplet material is longer than singlet material. Figure 7 shows optical response of the triplet material. Response time of switch on is 100 μs at 6V. It is faster than the shortest bit of the digital gray-scale.

Figure 8 shows the linearity of OLED display using the 6bit digital gray-scale control method. There is no degradation of gray scale linearity due to the transient of optical response.

Comparing singlet material display, the luminance of the triplet display shows four times brighter than the singlet materials at the same voltage, illustrated in Figure 9.

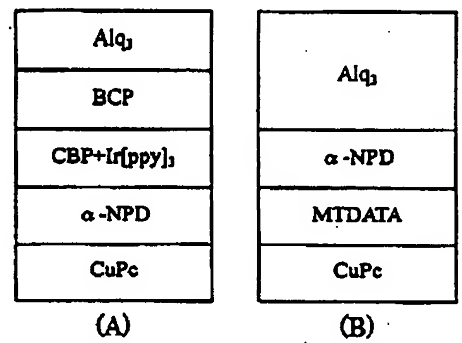


Figure 6 Structure of the OLED

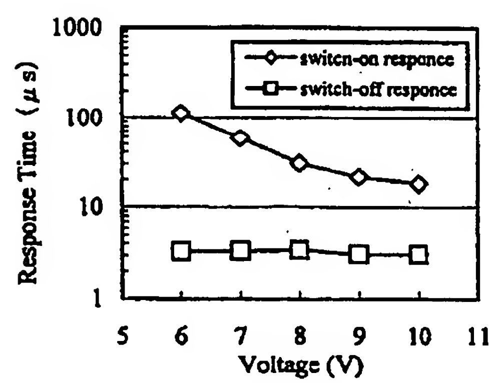


Figure 7 Relation between EL response time and applied DC voltage

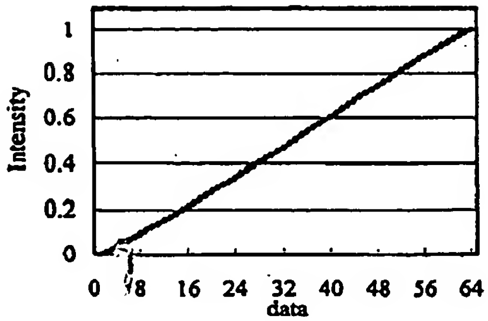


Figure 8 Gray scale linearity of the TFT-OLED display

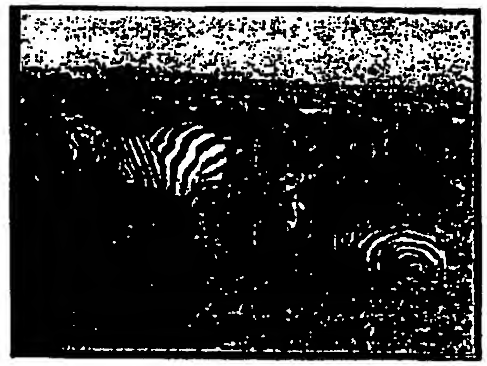


Figure 10 Photograph of Display Image of the triplet TFT-OLED

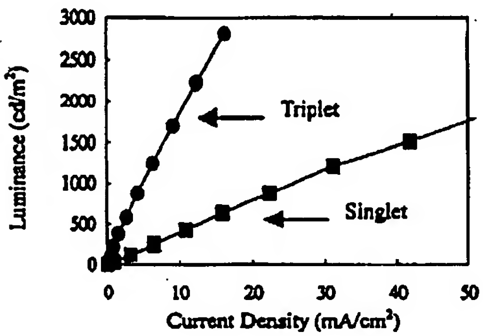


Figure 9 Relation between luminance and current density of OLED

Result

The ratio of emitting period in a whole flame period is 63% for 6bit gray-scale because of separating the emitting period and addressing period. However we can keep the high luminance without increasing the power consumption of the display. It shows that the combination of digital gray-scale method and triplet materials on the TFT display satisfies the demand of high quality, low power consumption.

Figure 10 shows the picture of the TFT-OLED panel, using the p-Si TFT substrate and triplet emissive center.

Using the high speed TFT, we succeeded the 64 gray scales by the time-ratio gray-scale. Moreover by the digital operation at the whole circuit on the substrate, we obtain the excellent uniformity of pixel luminance because the variation of TFT characteristics can be avoided.

Conclusion

We developed TFT-OLED display with the 64 digital gray-scale using triplet emissive center for the first time in the world. We present the excellent image quality of TFT OLED display. We show that the OLED display which combined technique, triplet material and p-Si TFT device. We believe that the display is ideal for a system of energy-saving mode.

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